

# Fabrication of long superstructure fiber Bragg gratings (SSFBG's) using a novel scanning phase-mask technique

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## ABSTRACT

*We propose a novel fabrication technique for long superstructure fiber Bragg gratings (SSFBG's) based on scanning phase mask and trimming of relative phases between FBG's. This technique enables to fabricate long SSFBG with a short phase mask. We fabricated successfully a 9cm-long SSFBG by cascading 3 pieces of 3cm-long SSFBG's.*

## 1. INTRODUCTION

Fiber Bragg gratings (FBG's) are essential filter devices for both telecommunication and sensor applications. Superstructure fiber Bragg gratings (SSFBG's) are especially attractive for wavelength-division multiplexing (WDM) systems because of their comb filter responses [1,2]. As the capacity of WDM systems grows, SSFBG's used in the WDM systems have to be broader and more densely spaced. To realize the broad-bandwidth and dense spacing, SSFBG's inevitably have to be long. In the conventional method, a long phase mask is needed to fabricate long SSFBG's. However, long phase masks are difficult to fabricate, and much more expensive. Therefore, the feasible length of SSFBG's is limited by the phase mask. This is a reason why many SSFBG's having various functions for the WDM systems have been proposed, whereas many of them have not yet realized. In this paper, we propose a novel fabrication technique for long SSFBG based on scanning phase mask and trimming of relative phases between FBG's. This technique can realize a long SSFBG using only a short phase mask. This is also applicable to fabrication of various kinds of SSFBG's.

## 2. PRINCIPLE OF SSFBG AND CONVENTIONAL FABRICATION METHOD

The SSFBG is a sampled FBG along the fiber axis (Fig.1(a)). The reflectivity of this SSFBG can be obtained from the coupled-mode theory, which predicts that every spatial Fourier component of the refractive index perturbation contributes a peak in the reflection spectrum. The Fourier components of the SSFBG can be obtained by

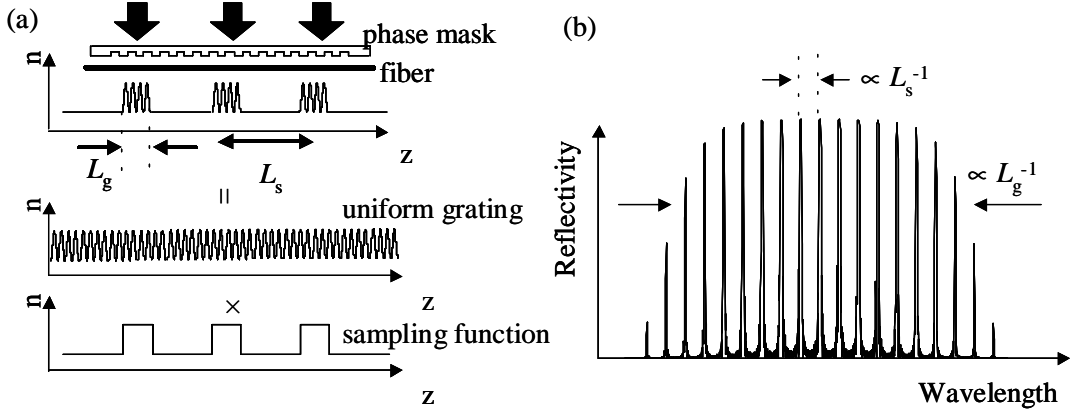


Fig. 1 (a) Superstructure fiber Bragg grating and its refractive index modulation. (b) The Comb of SSFBGs' reflectivity calculated from coupled-mode theory.

convolving the Fourier component of the uniform grating at the Bragg wavelength with the comb-like components of the sampling function (Fig. 1 (a)). Therefore, we obtain a comb-like reflectivity spectrum centered at the Bragg wavelength (Fig. 1(b)). The channel spacing and the bandwidth of the envelope of reflectivity spectrum are inversely proportional to the spacing of sampled FBG's ( $L_s$ ) and the length of a single sampled FBG ( $L_g$ ), respectively (Fig. 1(a,b)). To realize narrower channel spacing, FBG's spacing has to be wider. For example, supposing that a 100GHz-spaced SSFBG has the FBG spacing ( $L_s$ ) of 1mm, the FBG spacing ( $L_s$ ) has to be 2mm for a 50GHz-spaced SSFBG. Then, total length of SSFBG becomes twice to keep the total bandwidth and reflectivity. Thus, the narrower the channel spacing becomes, the longer the total length of SSFBG is. These long SSFBG's need a long phase-mask in the conventional fabrication method, where the phase mask and the fiber are fixed to each other during the fabrication, because the relative phase of refractive index modulation between adjacent sampled FBG's has to be same. Therefore, the length of SSFBG is limited by the length of the phase mask in the conventional method.

### 3. PROPOSAL OF SCANNING PHASE MASK TECHNIQUE

To overcome this limitation by length of the phase mask, we propose here a scanning phase-mask method. In this technique, we make a first piece of SSFBG in the conventional method at first (Fig. 2, *step-1*). Then we scan the phase mask along the fiber and make a second piece of SSFBG (Fig. 2, *step-2*). At this point the relative phase ( $\phi'$ ) of refractive index modulation between the two SSFBG's is not matched with the relative phase ( $\phi$ ) between adjacent FBG's within a piece of SSFBG. Therefore the reflection spectrum has a split because of interference between each SSFBG's. Complete phase matching is realized by the phase-shift using the refractive index change at the connection point. We irradiate uniform UV light without phase mask so that  $\phi'$  is equal to  $\phi$ . Thus, 2 pieces of SSFBG become a piece of SSFBG which is twice as long as the phase mask. Repeating these procedures, we can realize the long SSFBG which is several times longer than the phase mask.

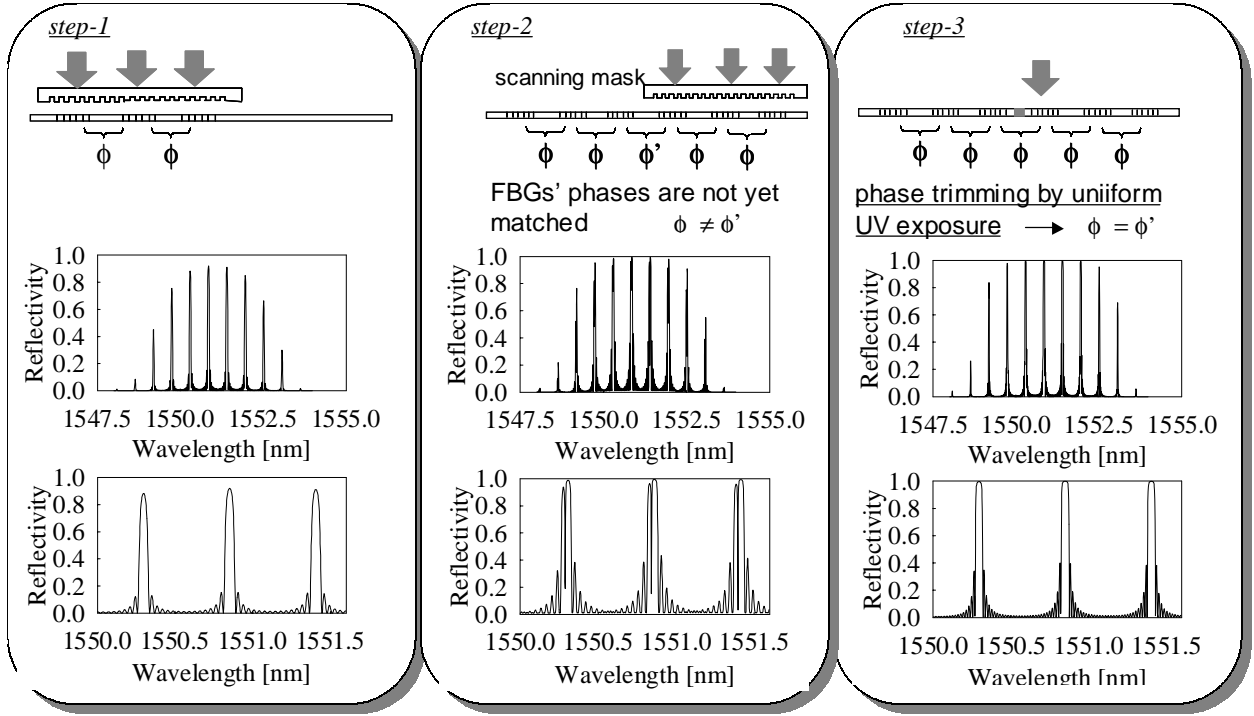


Fig.2 The scanning phase-mask technique is schematically explained.

#### 4. EXPERIMENTAL RESULTS

We experimentally demonstrate this phase-mask scanning technique. In our setup, a KrF excimer laser ( $\lambda = 248$  nm) was used for the UV light source. The pitch of uniform phase mask is 1072 nm, and the FBG spacing and the length of a single FBG are 3mm and 0.3mm, respectively. Fig.3(a) shows the reflection spectrum of 2 pieces of 3cm-long SSFBG's before trimming the relative phase between them (Fig. 2, *step1+step2*). Only by scanning the phase-mask along the fiber and fabricating 2 pieces of SSFBG's, their reflection spectrum is split to two peaks due to interference between SSFBG's. Then we irradiate the UV light without the phase mask to trim the relative phase  $\phi'$ , so that we can get ideal comb-like filter response. As the number of UV pulses is increased, one of the peaks grows up (Fig. 3(b)), and finally only one peak is selected (Fig. 3(c)). Sidelobes around the reflection peaks

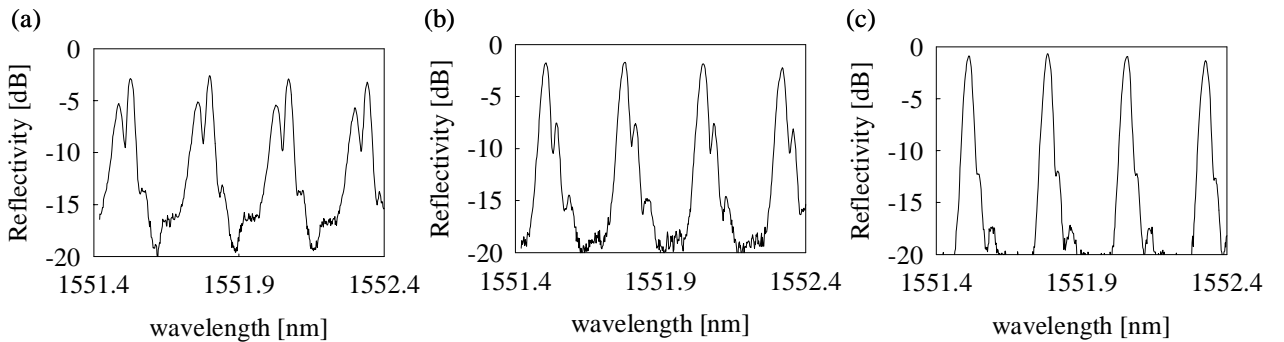


Fig.3 Change of reflection spectrum during trimming of the relative phase between 2 pieces of SSFBG's. (a) Before relative phase trimming. (b) Trimming is incomplete. (c) Trimming is complete.

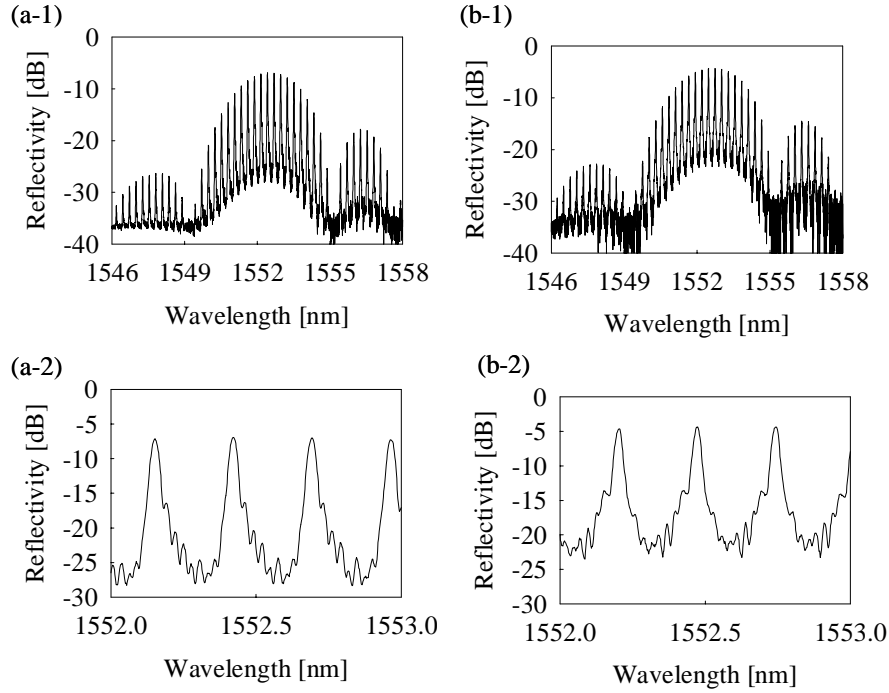


Fig.4 Reflection spectra of the SSFBG's. (a-1,2) A 3cm-long SSFBG fabricated by the conventional method. (b-1,2) 9cm-long SSFBG cascaded with 3 pieces of 3cm-long SSFBG fabricated by the scanning phase mask technique

can also be suppressed after trimming (Fig. 3(c)). Thus, we could fabricate a SSFBG twice as long as the phase mask.

Using this scanning phase-mask technique, we successfully fabricated a 9cm-long SSFBG by cascading 3 pieces of 3cm-long SSFBG. Fig. 4(a-1,2) is the spectrum of the 3cm-long SSFBG, and Fig. 4(b-1,2) is that of the 9cm-long SSFBG. We could realize higher reflectivity by 2.4dB in the 9cm-long SSFBG without losing total bandwidth of original SSFBG. At present, we can not yet fabricate the strong SSFBG ( $R \approx 1$ ) because of the UV power decline during fabrication. However, monitoring the UV light power and controlling the laser output, strong SSFBG's will be able to be fabricated. In this case, the long SSFBG will have broader bandwidth than the short SSFBG without losing high reflectivity.

## 5. CONCLUSION

We proposed a novel fabrication method for long SSFBG's based on scanning phase mask and trimming relative phases. Using this technique, long SSFBG's could be fabricated using a short phase mask. This technique can be used not only in normal SSFBG's fabrication but also in chirped SSFBG's fabrication. This can be very effective to overcome a limit of length of the phase mask.

## REFERENCES

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